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Effect of Patch Borders on Coercivity in Amorphous Rare Earth-Transition Metal Thin Films

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1 Motivation

The coercivity at the micron scale is a very important property of magneto-optical media [1, 2]. It is a key factor that determines the magnetic domain wall movement and domain reversal. In this report we discuss how the coercivity is influenced by a special type of patch borders. Patch formation is a general phenomenon in growth processes of amorphous rare-earth-transition-metal thin films [3]. Different patches may stem from different seeds and the patch borders are formed when they merge. Though little is known about the exact properties of the borders, we may expect that the exchange interaction at the patch border is weaker than that within a patch, since there is usually a spatial gap between two patches. This is the practical background of our work.

2 The System

Our computer simulations were performed on a two-dimensional hexagonal lattice consisting of 37 complete patches with random shape and size. Though we used the same lattice for the results to be represented in Figs. 1 and 2, the patch borders are only highlighted by the grey lines in Fig. 2. Some of the patches appearing in the boundaries of the lattice are actually different parts of the same patch, because of the periodic boundary conditions. Each patch has

its own axis of anisotropy, which is oriented randomly within a cone angle of $\Theta = 45^\circ$ about the perpendicular direction. Since the lattice has an area $0.256\mu\text{m} \times 0.222\mu\text{m}$, the average dimension of each patch is about 390 \AA . This dimension is large in comparison with the width of domain wall ($\simeq 100 \text{ \AA}$) in the present situation.

The following set of parameters were used in the simulations: saturation magnetization $M_s = 100 \text{ emu/cm}^3$, anisotropy energy density constant $K_u = 10^6 \text{ erg/cm}^3$, exchange stiffness coefficient within the patches $A_x = 10^{-7} \text{ erg/cm}$, film thickness $h = 500 \text{ \AA}$, Gilbert damping constant $\alpha = 0.5$, gyromagnetic ratio $\gamma = -10^7 \text{ Hz/Oe}$. Different values are assigned to the stiffness constant A_x at the patch borders. For the five patches containing a reversed domain (see Fig.1), starting from the lower left corner and moving counterclockwise, the stiffness constant on the patch borders are 10 %, 20 %, 50 %, 40 % and 30 % of the nominal value (i.e. 10^{-7} erg/cm). The stiffness constant on all of the remaining patch borders are 50 % times 10^{-7} erg/cm . There are two reasons for setting different exchange constants at the borders. One is that in reality the borders may be different, the other is that we can simulate different cases in a single computer run. The anisotropy constant at the central disk of each reversed domain is 10^7 erg/cm^3 (i.e. 10 times the nominal value of K_u), because otherwise these initial nuclei will not be stable.

3 Results

Fig.1 (a) shows the initial magnetization state. Five reversed domains were artificially built in the above mentioned special patches. The patch borders are not highlighted. Following the direction change in each of the domain wall, we see that the accumulate winding angle is equal to 2π for each domain wall. Now we let this initial magnetic state relax for $t = 0.5 \text{ ns}$ to the remanent state. To make sure that this state is close enough to the equilibrium state, we also made snapshots of the magnetization at $t = 0.3 \text{ ns}$ and 0.4 ns and found no difference between them. The remanent state is illustrated in Fig.1 (b). Now we see that the lower left domain

has two dramatic changes, while the remaining four domains remain more or less unchanged. One change is that the domain expands to the north border of the patch. The reason is that, the domain wall is initially very close to the border which has a very low exchange energy (10 %). Therefore, it sticks to the border, just as a domain wall sticks to a void region [1, 2], to make the minimum wall energy. The other change experienced by this domain is that the winding number becomes zero, i.e. the dipoles in the domain wall region align in the same direction. If there were no border, the winding number would not have been changed, since changing a winding number must experience a stage where anti-parallel dipoles are generated, which corresponds to a higher exchange energy. In the present case of weak exchange coupling, the winding angle can be changed because there is no such energy barrier.

In order to investigate the coercivity of domain wall motion, we applied a magnetic field in the negative z-direction to the lattice. At first, we applied a field of $H_z = -1000$ Oe. Fig.2(a) is a snapshot of the steady state at $t = 1.3$ ns. Here we see that the lower left domain expands to fill the whole patch. This means that, when the reversed domain is near a border with weak exchange interaction, the coercivity of domain wall motion is very low. The reason is that the magnetization outside the patch cannot exert a sufficient exchange force to keep the dipoles inside the patch upwards. At the next stage, we increase the strength of the applied field to $H_z = -1500$ Oe and let the system start from the state of Fig.2(a). Fig.2(b) shows the new steady state at $t = 2.45$ ns. Since the exchange interaction is too weak, the reversed domain in the lower left corner does not influence too much on the magnetization outside the patch. This means that, for the magnetization outside (and near) that patch to reverse, i.e. the domain wall moves beyond the patch, the external field must overcome the nucleation coercivity, but not the wall motion coercivity. To estimate this nucleation coercivity, we neglect the demagnetizing field and the 10 % exchange interaction and consider the patch border as a straight open border. Then it is easy to find out that the critical magnetic field strength to reverse the magnetization at the open border is about 40 % of the anisotropy field. In the present case this critical field is equal to -8 kOe, which is obviously much stronger than what we applied to the film (-1.5

kOe). Therefore, for a patch with weak exchange borders, we can conclude that the inside reversed domain can easily expand to fill the patch, but it is difficult to move beyond the patch border. This picture also applies to the patch whose borders have 20 % exchange constant, see the reversed domain in the lower right corner in Fig.2(b). In contrast to these two cases, the reversed domain in the extreme right with borders of 50 % exchange strength and that in the upper central patch with borders of 40 % exchange strength do not expand too much, because for stronger exchange borders, the coercivity of wall motion is higher.

The reversed domain in the upper left corner whose borders have 30 % exchange strength in Fig.2(b) shows a compromise case. In this case, we see that the coercivity of domain wall motion is less than 1500 Oe and yet, when the domain reaches the borders, the exchange force produced by the reversed domain inside the patch and the external field together makes the domain expand a little bit outside the patch borders. It then stops because the exchange interaction inside a patch is strong and so is the coercivity of domain wall motion. Now we increase the applied field to $H_z = -2000$ Oe and let the system start from the state of Fig.2(b). Fig.2(c)-(e) are snapshots of systems at $t = 0.95$ ns, 1.25 ns and 1.55 ns. Now we see that the applied field is stronger than the coercivity of wall motion and the four domains with relatively stronger exchange interaction borders expand, and until eventually all the lattice is reversed (not shown in the figure). In the process of domain expansion, we see that the domain in the lower left corner does not expand, because the applied field is still weaker than the corresponding nucleation field, i.e. $\simeq -8$ kOe, as was mentioned before.

From this series of simulations we may conclude that the domain in the patch with borders of 30 % exchange strength can expand most easily to the whole lattice, because the exchange strength of the border is not too high to prevent the domain from growing within the patch and it is not too low to prevent the domain from expanding beyond the patch.

References

- [1] R. Giles and M. Mansuripur, *Possible sources of coercivity in thin films of amorphous rare earth- transition metal alloys*, Computers in Physics, (1991).
- [2] M. Mansuripur, R. Giles and G. Patterson, *Coercivity of domain wall motion in thin films of amorphous rare earth-transition metal alloys*, J. Mag. Soc. Japan. Vol. 15 (1991) pp.17-30.
- [3] R. B. Sargent, *Surface diffusion: a computer study of its effects on thin film morphology*, Ph.D thesis, Optical Sciences Center, University of Arizona, 1990.

Figure Captions

Fig.1 (a) The initial state has five reversed domains. These domains are located inside patches whose borders have 10 % (lower left), 20 % lower right, 30 % (upper left), 40 % (upper right) and 50 % (middle right) exchange strength. (b) The remanent state after relax from the state (a) for 0.5 ns.

Fig.2 Evolution of the magnetization under an applied field. (a) The steady state under $H_z = -1000$ Oe is reached after $t = 1.3$ ns starting from the state of Fig.1(b). (b) The steady state under $H_z = -1500$ Oe is reached after $t = 2.45$ ns starting from (a). (c)-(e) Evolution starting from (b) under $H_z = -2000$ Oe at $t = 0.95$ ns, 1.25 ns and 1.55 ns.

(a)

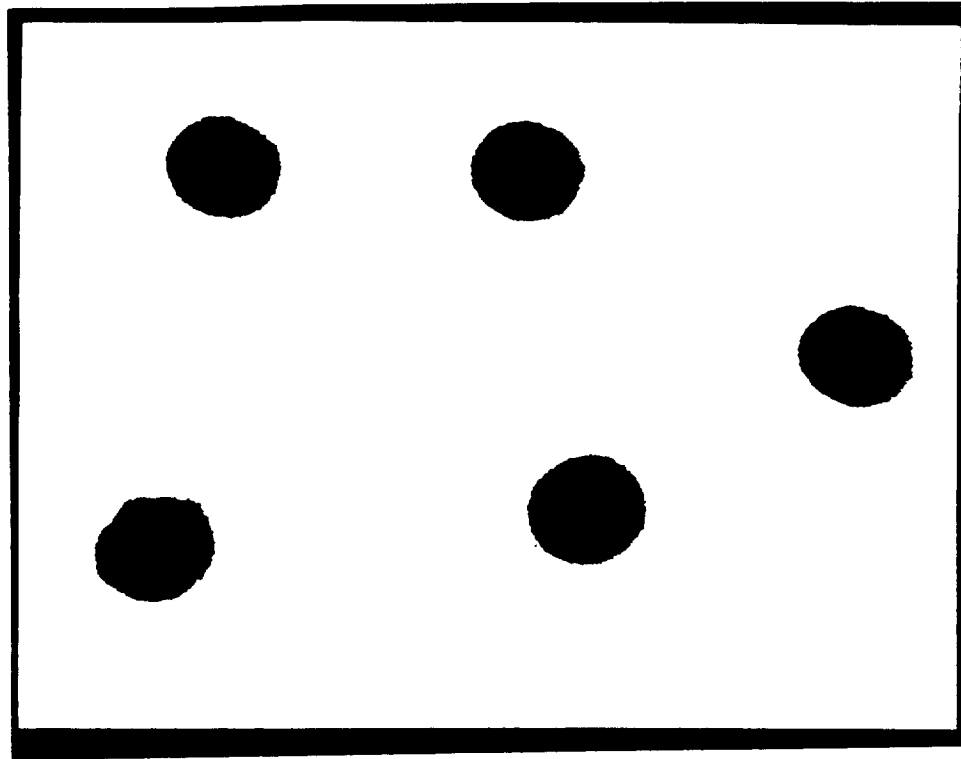
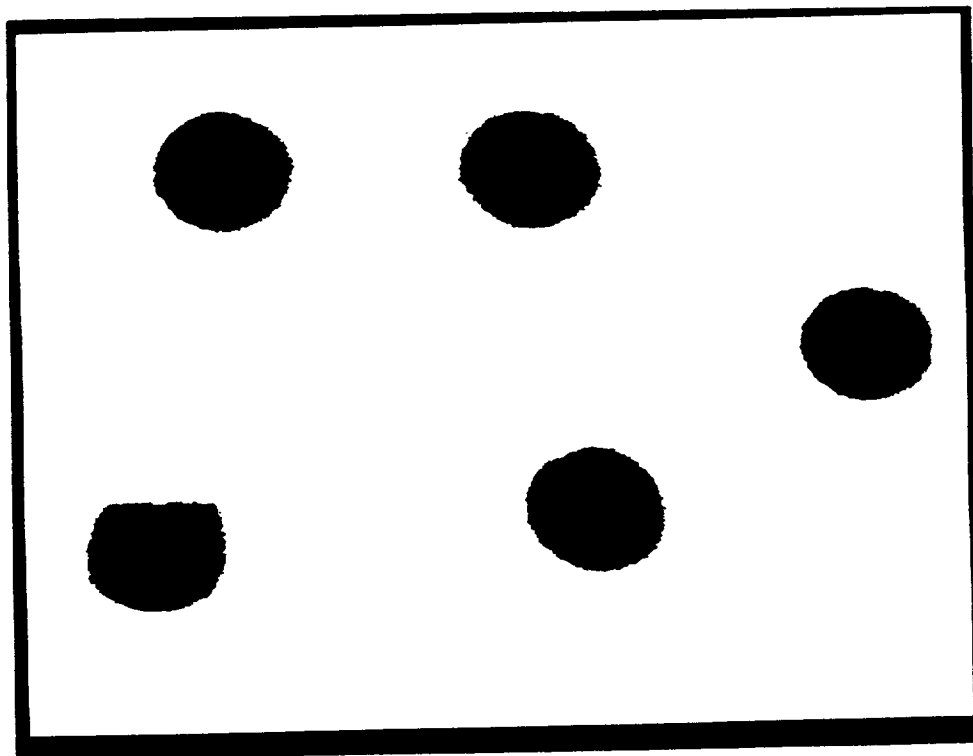


Fig. 1

(b)



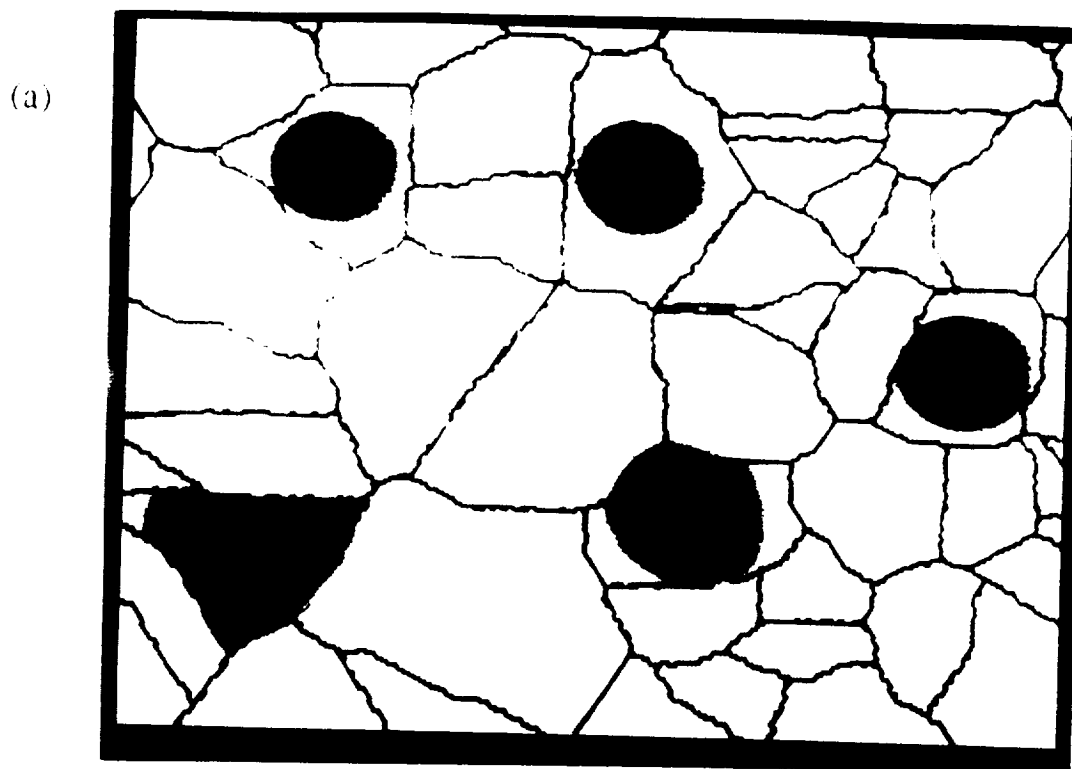
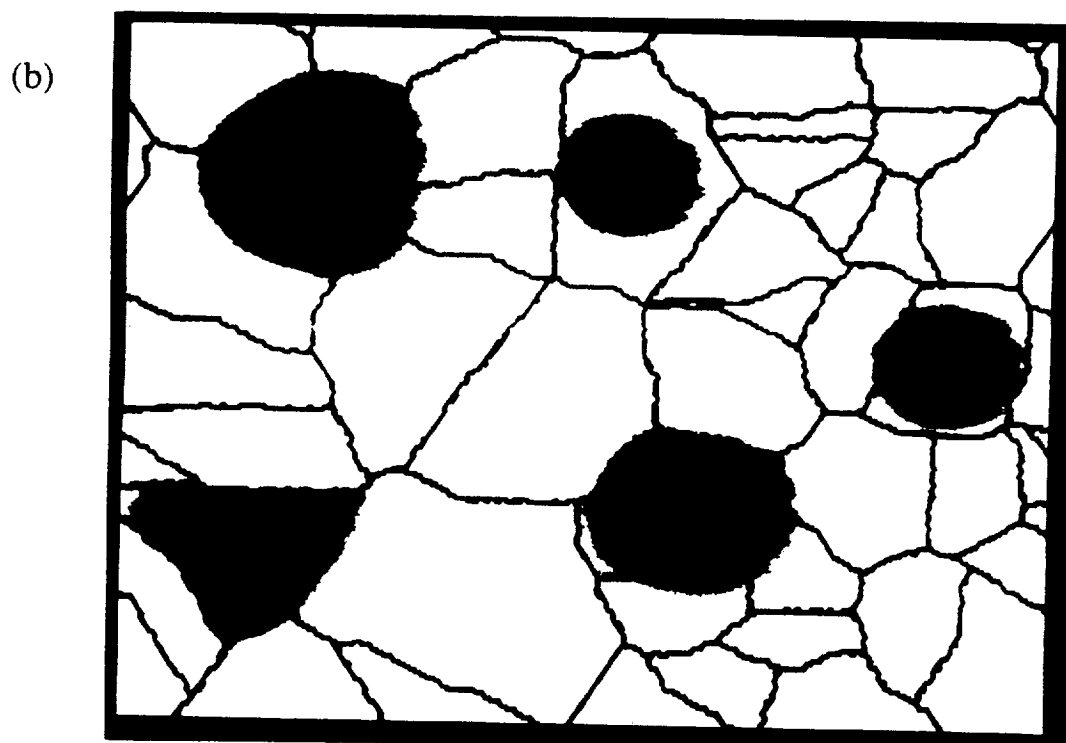


Fig. 2



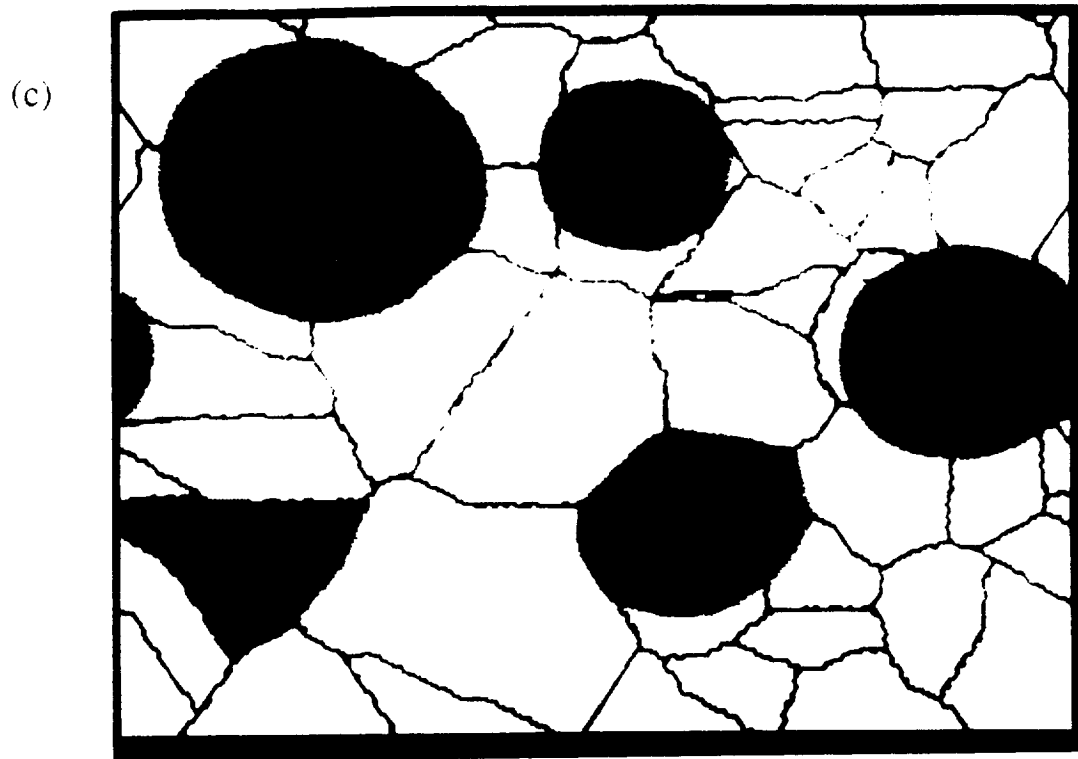
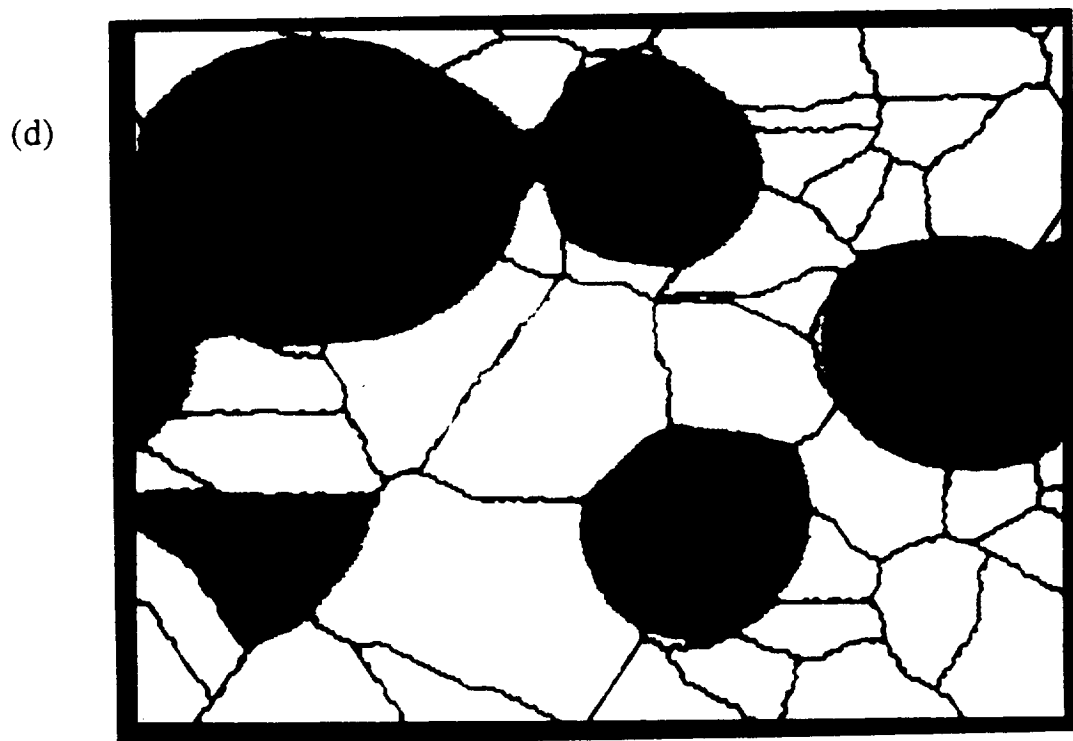


Fig. 2



(e)

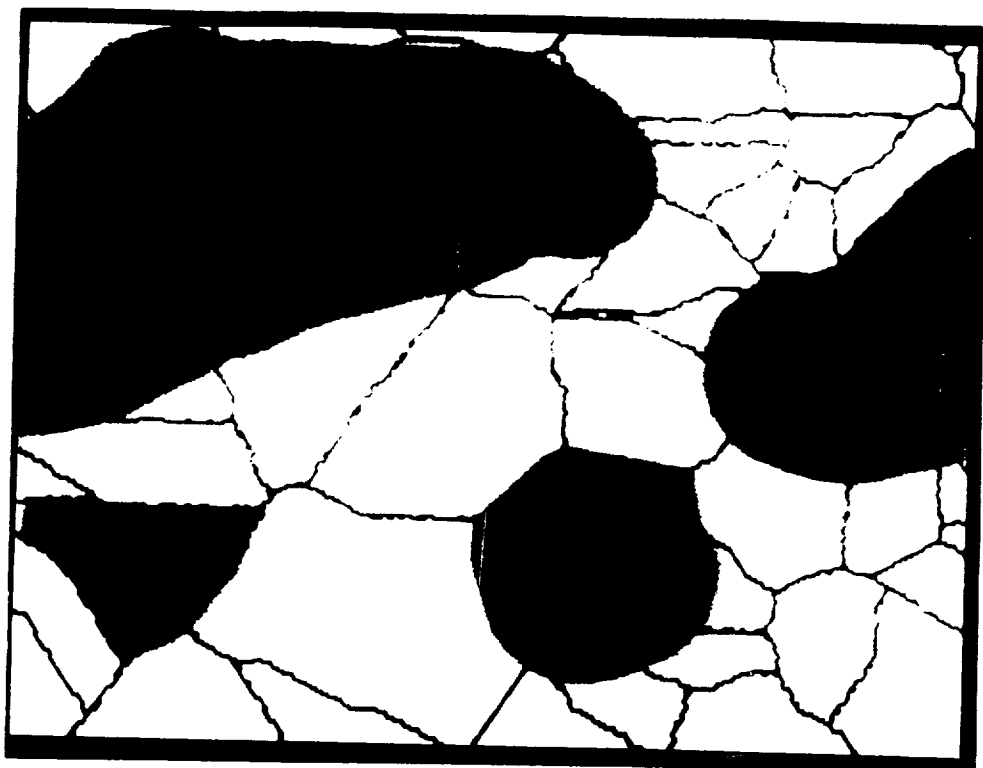


Fig. 2